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TITLE: OPTICAL METHODS OF MEASURING THE ROUGHNESS OF THE SURFACES OF HIGH PRECISION STEEL BALLS

Yan Shen, Zhang, E.

SUMMARY This article introduces a type of lens reflection section which makes use of laser light in connection with rough surface scattering to carry out methods for measuring the degree of roughness of high precision ball surfaces. The principles in this type of method are reliable. The design of the instruments is simple. Production costs are low. The environmental requirements are not high. Along with this, it is possible, on the presuposition that light path adjustments are not carried out, to carry out measurements on steel balls with different radii. It is suitable for checks at the production site.

I. A General Description of the Method

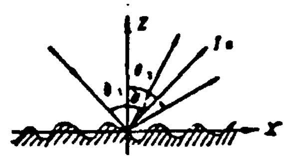

Fig. 1.

On the basis of the theory of light scattering[1], when a one beam unit strength straight laser beam is fired into a rough surface, the scattered light scatters into space toward various individual directions (Fig.1). If changes in the height of the surface correspond to a Gauss distribution, and, moreover, the autocorrelation function of the surfaces are unitary Gaussian functions, for this type of one-dimensional random or stochastic surface, the light scattering distribution is:

$$I(\theta_2)=e^{-(V_zR_q)^2}\left(\mathrm{sinc}\,V_xL+\frac{\sqrt{\pi}\,F^2T}{2L}\sum_{m=1}^{\infty}\frac{(V_zR_q)^{2m}}{m!\,\sqrt{m}}\cdot e^{-V_x^2T^2/4m}\right) \qquad (1)$$

In this, T is the surface coherent length. L is the area or length of the surface being measured.

$$V_x=\frac{2\pi}{\lambda}(\sin\theta_1-\sin\theta_2); \quad V_z=\frac{2\pi}{\lambda}(\cos\theta_1+\cos\theta_2);$$

$$F=[1+\cos(\theta_1+\theta_2)]/\cos\theta_1(\cos\theta_1+\cos\theta_2)$$

When considering high precision surfaces (weakly scattering surfaces), formula (1) can be simplified to be:

$$I(\theta_2)=e^{-(V_z R_q)^2}\cdot\left[\mathrm{sinc}\,V_x L+\frac{\sqrt{\pi}\,F^2T}{2L}(V_z R_q)^2e^{-V_x^2T^2/4}\right] \tag{2}$$

When speaking in terms of the direction of lens or mirror reflection,

$\theta_2=\theta_1$, $V_x=0$, $V_z=$

$\frac{4\pi}{\lambda}\cos\theta_1$, $F=1$, 另外, T/L 远远小于 1,

Besides this, T/L is much, much smaller than 1. In this way, it is possible to obtain lens or mirror reflection illumination:

$$I_s=I(\theta_1)=e^{-(\frac{4\pi}{\lambda}R_q\cos\theta_1)^2} \tag{3}$$

Deriving from equation (3), the strength of the incoming light is assumed to be a unit strength. If the strength of the incoming light is I_0, in situations that do not consider absorption,

$$I_s=I_0 exp\left[-\left(\frac{4\pi}{\lambda}\cos\theta_1\right)^2R_q^2\right] \tag{4}$$

For other scatterings of a flood of light:

$$I_d = I_0\left(1 - exp\left[-\left(\frac{4\pi}{\lambda} R_q \cos\theta_1\right)^2\right]\right) \quad (5)$$

It is possible to make use of the ratio , P, between the lens or mirror reflected illumination I_s and the scattered illumination under a flood of light I_d in order to precisely measure the degree of roughness of a surface:

$$P = I_s/I_d = I_s/(I_0 - I_s) \quad (6)$$

This type of method is relatively easy to effect when one is concerned with measuring the degree of roughness of flat surfaces. If, in front of the receiving instrument, one adds a set of transformation lenses, the center strength of the spectrum surface is, then, I_s. The peripheral strength distribution is then the scattering strength value (I_d for different scattering angles. 14
However, speaking in terms of ball or spherical surfaces, and, in particular, this means measuring the degree of roughness of ball or spherical surfaces which have small radii of curvature, one then faces a relatively difficult situation. If one is using a general parallel light input radiation, spherical surfaces that have different radii of curvature have different scattering distributions. From Fig.2 it is possible to see the situation concerning lens or mirror reflected light distributions when a beam of parallel light is radiated into two spherical surfaces that have different radii of curvature. Due to the limitations of optical systems and receiving instrument apertures; requirement for a complete receiving surface light scattering distribution is a difficult one. It requires special photoelectric instruments and optical systems. However, it only requires an appropriate selection of light path and the carrying out of complete measurements of I_0 is possible. We designed an experimental apparatus and carried out measurements of I_s, I_0 As a result of this, we obtained information on the degree of roughness of surfaces.

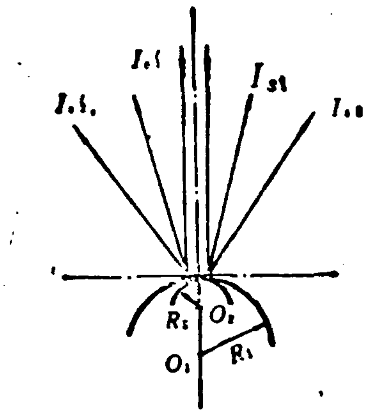

Fig.2

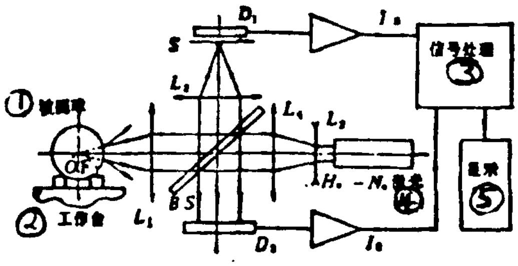

Fig.3

(1) Sphere Being Illuminated (unclear) (2) Operations Platform (3) Signal Processing (4) Laser (5) Display

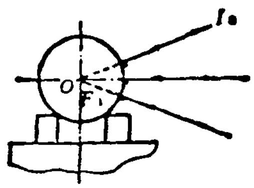

Fig.4

As can be seen from Fig.3, after the collimnation and beam spreading of the beam radii of lasers L_3 and L_4, and, after a portion of the light radii goes through the semi-transmittig, semi-reflecting plate BS, it again goes through L_1 and forms beams that are collected into a gathered light beam. The forward or anterior focus point and the center of the sphere being measured are coincident. In this way, as is shown in Fig.4, the light rays which are radiated onto the surface of the sphere are all perpendicular to the surface of the sphere. The light rays reflected by lens or mirrors retrace their original routes. After going through L_1, they are, again, reflected through BS and will be gathered at the posterior focus of L_2. At the center point of the posterior focus surface of L_2, there is positioned a small aperture light stop S. Going through a device for detection and measurement, detector D_1 ; it is then possible to measure $I_{(unclear)}$. After going through collimation, a different portion of the light, following its reflection by BS, is directly received by detector D_2. One obtains $I_2 = aI_0$. Going through experimentation to precisely specify appropriate a values, it is then possible to obtain $I_0 = I_2/a$. If one make Q equal to the ratio between the strength of lens or mirror reflected light and the strength of light radiated in, and $Q = I_1/I_0$, and, also, because the perpendicular incoming radiation $\theta_i = 0°$ from equation (1)

$$(1)\ Q = I_1/I_0 \Rightarrow$$

$$exp[-(4\pi R_q/\lambda)^2]$$

$$R_q = \frac{\lambda}{4\pi}\sqrt{L_n\left(\frac{1}{Q}\right)} \qquad (7)$$

Due to the fact that $P=Q/(1-Q)$, in this way, it is only necessary to arrive at Q, and one can indirectly also obtain the ratio P between lens or mirror reflected light and full scattering. This type of light path placement formation can guarantee that $I_\circ$ enters completely into the optical system. At the same time, it is also able to effectively eliminate the effects of wave movements in light sources. It also makes no special demands on optical systems.

II. EXPERIMENTAL ANALYSIS

We used the equipment shown in Fig.3 to carry out measurements on a set of samples with different diameters. This set of steel spheres, on the basis of the ZQ23-84 standard, were first run through standardization with the Talysurf 5 contact probe test device. The actual parameters are as shown in Table 1.

(1) 编号	1	2	3	4	5	6	7
(2) 直径 mm	7.94	15.08	12.30	25.40	4.76	15.08	17.47
R_a 触针 μm (3)	0.007	0.008	0.009	0.016	0.020	0.054	0.059

Table 1

(1) Serial No. (2) Diameter (3) Contact Probe

Table 2 is the measurment values obtained through experimentation. The R_a light in Table 2 is used to indicate the R_a values measured by optical methods. Fig.5 is the correlation between contact probe test instrument and optical methods. 15
From this Fig., it is possible to see that the two types of methods show a very good correspondence or uniformity. Besides this, during experimentation, it was also discovered that the requirements of this

type of method on the degree of precision of the placement of the center of the sphere were not high. It was only necessary the error in position placement not exceed 40μm and that was able to satisfy measurement requirements. In this way, general adjustments and minute movements of structures were able to satisfy requirements.

①编 号	1	2	3	4	5	6	7
$Q = I_t/I_0$	0.970	0.950	0.933	0.893	0.620	0.207	0.143
$P = Q/(1-Q)$	32.33	19.00	13.93	8.35	1.63	0.260	0.170
R_a ②, μm	0.007	0.009	0.011	0.014	0.028	0.051	0.058

Table 2

(1) Serial No. (2) Light

III. CONCLUSIONS

Experimentation clearly demonstrates that this method, when used to measure the degree of roughness of high precision spherical surfaces, is feasible. This type of method has the several special features outlined below.

(1) System principles are clear and precise. Structures are simple. Production costs are low.

(2) Operation is simple. It is possible, on the presupposition that light paths have been adjusted, to carry out measurements of spherical surfaces with different radii of curvature.

(3) As far as the fact that requirements for the operating environment are not high is concerned, it is appropriate to the carrying out of high speed quality control at the production site. However, the method in question is only capable of being used to measure spherical surfaces that have been processed using similar techniques of processing or working. As far as the checking and testing of different materials is concerned, the measurement of

surfaces processed or worked with different techniques still awaits further research and investigation.

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